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Non-Shock Initiation of Explosives

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Preface

Los Alamos National Laboratory is an incredible place. It was conceived and born amidst the most desperate of circumstances. It attracted some of the most brilliant minds, the most innovative entrepreneurs, and the most creative tinkerers of that generation. Out of that milieu emerged physics and engineering that beforehand was either unimagined, or thought to be fantasy. One of the fields essentially invented during those years was the science of precision high explosives. Before 1942, explosives were used in munitions and commercial pursuits that demanded proper chemistry and confinement for the necessary effect, but little else. The needs and requirements of the Manhattan project were of a much more precise and specific nature. Spatial and temporal specifications were reduced from centimeters and milliseconds to micrometers and nanoseconds. New theory and computational tools were required along with a raft of new experimental techniques and novel ways of interpreting the results. Over the next 40 years, the emphasis was on higher energy in smaller packages, more precise initiation schemes, better and safer formulations, and greater accuracy in forecasting performance. Researchers from many institutions began working in the emerging and expanding field.

In the midst of all of the work and progress in precision initiation and scientific study, in the early 1960s, papers began to appear detailing the first quantitative studies of the transition from deflagration to detonation (DDT), first in cast, then in pressed explosives, and finally in propellants. Clearly this phenomenon had been observed before, and was undoubtedly the cause of many accidents, but with the improved diagnostic techniques (e.g., image-intensified cameras, rapid oscilloscopes, etc.) workers were finally able to begin to probe this very difficult area of reactive material behavior. These formed the initial studies of what has come to be known as nonshock initiation. This behavior and the reasons it is so difficult to understand are explored in Chap. 1.

If an explosive is going to react violently, an ignition event must occur at some location within the volume. That ignition will be at a single point, perhaps in a small portion of a crystal. Whatever its size, to propagate the reaction, mass, momentum, and energy must be conveyed (conducted, convected, radiated, or advected) to other locations on a timescale that promotes growth of temperature and pressure. Transport phenomena have been studied for hundreds of years, but in the context of nonshock initiation, we felt that a complete presentation was required to place the common terms into context. This forms the substance of Chap. 2 by Perry.

Explosives are metastable molecules – they are always reacting, but the rate is extremely temperature sensitive. Depending on the material and temperature, the reaction rate can double with an increase of only a few degrees centigrade. The physics and chemistry governing this behavior are extremely complex. For example, the decomposition of HMX has been described with over 500 elementary kinetic steps, and it is known that this is not a complete treatment. Trying to use that kind of description to understand the behavior of a reactive system is impossible, even with the latest state-of-the-art computational capabilities. We require a more global approach to the entire decomposition process. The ability to do that requires enormous insight, a fundamental understanding of chemistry, and the capability of reducing processes to their most simple, yet complete, level. But no further. Henson has done just that in Chap. 3.

Once initiated, an explosive grain, or hot spot, can either fail, survive for a short amount of time, or progress and grow. This is the problem of criticality, and without knowing how this process occurs, it is impossible to understand or predict the outcome of an initiation event. In Chap. 4, Hill discusses in detail the important issues surrounding the topic of criticality, upon what it depends and how it affects the outcome of an event.

If a hotspot survives, the reaction may then proceed through the body of material. This process is called combustion, and involves the conversion of a solid material having chemical energy into gas at much higher temperature and pressure. The rate at which this occurs is governed by the kinetics, but the process is controlled by how the mass, momentum, and energy move. Combustion waves can progress at very slow speeds (fractions of a centimeter per second) or up to supersonic speeds in cracks. Clearly, the mechanism of combustion is central to the concept of nonshock initiation and is covered by Jackson in Chap. 5.

HMX is a very powerful explosive, but at atmospheric pressure and no confinement, it burns very slowly and in a laminar fashion. However, allow the pressure to increase somewhat, and provide surface area and confinement, and that lazy laminar combustion wave can easily convert into a detonation wave with pressures of thousands of atmospheres. In Chap. 6, Parker and Rae discuss the damage mechanisms that create the surface area without which the transition to detonation cannot occur in secondary explosives. This is an area of study of relatively recent vintage and which some have been slow to acknowledge. However, our ability to directly observe reacting systems being damaged has increased substantially in the past 10 years, enabling these conclusions to be considered incontrovertible.

Chapter 7 discusses the topic of cookoff, which comprises each of the topics discussed before. It is a general term that includes explosion as well as detonation. The chapter discusses the small and large-scale tests used to study the field of nonshock initiation and some of its important elements.

The deflagration to detonation transition was alluded to in an earlier paragraph and is discussed in other portions of the text, but it needed a chapter of its own to be elucidated more fully. The earliest papers accurately described the overall behavior of explosives, but in many cases missed the quantitative response. In Chap. 8 McAfee provides a complete treatment of the DDT process incorporating all of the advances that have recently occurred, and unifies many of the observations that have been made over the past 50 years.

It is possible to drop a relatively large piece of explosive from a substantial distance onto a very hard surface and have no reaction. However, take that same explosive part, and the same hard surface and add a few grains of sand, and an entirely different outcome obtains. The study of frictional initiation has a long history with many elegant experiments having been conducted. Dickson provides a well-reasoned and complete analysis of the topic in Chap. 9.

Finally, in Chaps. 10 and 11, Kennedy covers the areas of initiation by shear and impact, followed by spark and laser. These topics are sometimes overlooked because they are not very well characterized, but the first three constitute primary sources of accidental nonshock initiation, and the last is a current topic of study for purposeful ignition of explosives.

We hope that readers will see the organization of the text as a natural progression in the study of nonshock initiation. It is by no means an easy field of study, nor one in which all of the major questions have been worked out. Each of the authors of this volume is not only an expert in the field, but someone who has thought deeply about the topic. It took several years to formulate the concepts, reduce them to the written word, and then finally produce something worthy of publication. Each has been a great resource and an important and trusted colleague for many years. I am indebted to each one for his contribution to my understanding of the field. I also acknowledge the work of Phil Howe, without whose tireless and persistent support many of the experiments and analyses discussed in this text would not have occurred. He is an integral and crucial member of the team.

I have been incredibly fortunate to have known some of the most influential men and women in the field of explosives research. At Los Alamos, I was instructed in DDT by Wayne Campbell, shock physics by Mac Walsh, detonation physics by Bill Davis and John Bdzil, detonation chemistry by Ray Engelke, propellant behavior and explosives safety by John Ramsay, shaped charge design by Bill Mautz, and the list goes on. I have also had the privilege of meeting pioneer researchers from throughout the world ranging from Kondrikov and Dremin from Russia to Price and Jacobs from White Oak. As funding and support for the kind of work we do erodes, the community is becoming ever smaller. I am grateful to have been involved during some of the high points.

I want to thank my closest coworkers of many years, Laura Smilowitz, Bryan Henson, Steve Son, John McAfee, and Peter Dickson. The thousands of hours spent in discussion, writing, some arguing, and waiting for that elusive exotherm have been joyous.

Finally, I acknowledge the inestimable influence of my four children who have each exceeded every expectation of which I could have ever conceived, and my wife and eternal companion, Patrice, who completes me.

Los Alamos, NM, October 2009 *Blaine W. Asay*